Educational Robotics for Teaching Computer Science in Africa - Pilot Study

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Abstract. Educational robotics can play a key role in addressing some of the challenges faced by higher education institutions in Africa. A remaining and open question is related to effectiveness of activities involving educational robots for teaching but also for improving learner's experience. This paper addresses that question by evaluating a short pilot study which introduced students at the Department of Computer Science, University of Ghana to robot programming. The initial positive results from the study indicate a potential for such activities to enhance teaching experience and practice at African institutions. The proposed integrated set-up including robotic hardware, software and educational tasks was effective and will form a solid base for a future, full scale integration of robotic activities into the undergraduate curricula at this particular institution. This evaluation should be valuable to other educators integrating educational robots into undergraduate curricula in developing countries and elsewhere.

1 Introduction

Higher education is considered to be one of the biggest challenges, but also opportunities for developing countries. This is especially true for Sub-Saharan Africa which did not even experience the growth of wealth seen by other developing countries [19]. The challenges faced by African institutions are diverse, ranging from limited economic capabilities to old-fashioned pedagogic methodology, failing to engage and teach students effectively. There were some recent efforts made by selected African institutions to improve the quality of teaching and learning by the adoption of educational robotics [15, 3]. Such initiatives follow a belief that robots are an effective means to facilitate more engagement, higher motivation, and the development of practical skill sets, beyond the focus of robotics itself. In our own work [6], we have analysed the effectiveness of robotics as a subject to convey a larger skill set to students, where the positive effect is gained from the "embodiment" and physical presence of robots. This makes the outcomes of practical activities very vivid and immediately accessible, providing a continual formative assessment of learning progress and encouragement to students. Despite all that, an open question remains on how effective are such initiatives both for teaching practical skills but also for improving learner's experience.

To make contribution towards this debate, our paper evaluates the potential of robotic activities to enhance teaching and learning of generic programming skills at African institutions. The study involved short, three-week activities which introduced students at the Department of Computer Science, University of Ghana to robot programming. The activities were embedded into one of the relevant courses on computer architecture and principles of programming. The survey results from these activities indicate that educational robotics is a promising direction for both improving student's learning but also their engagement in practical sessions. From a practical point of view, we were also able to identify any major shortcomings of the integrated set-up consisting of robotic hardware, software and educational tasks before attempting a full scale integration into the undergraduate curricula. The proposed set-up can be very effective in learning specific programming concepts providing the educational tasks are carefully designed for that purpose. This evaluation should be valuable to other educators in developing countries and elsewhere working with educational robots and help them to identify the best ways of embedding educational robotics into teaching activities in developing countries to ensure that its adoption can support learners, teachers and institutions to realise their aims [7]. Our work is complementary to other initiatives undertaken in this part of the world described in the following section, but it is specifically targeted at general programming skills and university students.

2 Related Work

Educational theorists believe that robotics activities have tremendous potential to improve classroom teaching [17]. They argue that learners can gain a sense of power over technology by creating an environment where they can program and affect behaviour of a physical artefact [18]. This can happen at different stages of education starting with children [11] and reaching higher education [16]. It is important here to stress that educational robots cannot be considered as a 'magical' solution to all educational problems but as an *educational tool* which needs to be evaluated in different contexts including different educational stages, subjects learnt, its engagement effectiveness, etc.

Different aspects of using educational robots for enhancing teaching and learning activities were considered so far. For example, [5] observed a positive influence of such activities on overall learning performance and motivation. Other studies have revealed that educational robots can communicate effectively and enhance student enjoyment and engagement in classrooms [13, 10] and that effects are stronger than using other technology tools such as videos for example [20]. There is also evidence that shows that educational robotics can improve the problem solving skills [4, 14]. Additionally, educational robotics can encourage cooperation learning and teamwork among students. In the assessment of the specialist mobile robotics course [16], the authors pinpoint the fact that the course was able to meet deeper goals of developing domain-general interest but also teamwork and cooperation that can prepare students for broad success in technology and science education.

In order to take advantage of the benefits provided by educational robotics, some institutions in Africa have started to use the robots for teaching activities. In Ghana, for example, Carnegie Mellon University, USA in partnership with Ashesi University in Accra, developed an undergraduate introductory robotics course teaching students how to design, build and program robotic systems [15]. The main purpose of this initiative was to encourage students to recognise the scope of computer science and to enhance their technical creativity and problem solving abilities. In South Africa, University of Cape Town teamed up with Aachen University, Germany to design an inexpensive robotic platform for use in RoboCup Junior competitions and primary education [3]. Other initiatives of pan-national relevance include African Robotics Network (AFRON) [1]. AFRON brings together a number of organisations from the entire world interested in developing robotics-related education, research and industrial projects in Africa. One of the main activities organised by AFRON is the "Ultra Affordable Educational Robot" challenge with the scope of designing and building functional robotic platforms costing an order of magnitude less than commercial robotic products. This competition also highlights the current trend in designing modern educational robotics platforms, which need to provide not only functional hardware components but also easy to use programming environments and supplementary teaching material.

3 Pilot Study

Our general aim is to introduce educational robots into an undergraduate Computer Science curricula at African universities and assess its usefulness as a tool for enabling active teaching and learning practices; with the aim to go beyond the knowledge about robots, but rather using them as a means to teach computer science more generally. The main purpose of the proposed pilot studies was to identify technical and pedagogical issues and any potential limitations of using robots for teaching at African institutions. In this section, we present an integrated set-up consisting of the robot platform, dedicated software environment and designed activities, and evaluation methodology for assessing the initial potential of the robotic-enhanced workshop activities.

3.1 Overview

The proposed pilot study was embedded into teaching activities at the Department of Computer Science, University of Ghana. The selected subject was a core "Introduction to Computer Science II" course which teaches basics of computer architectures and programming principles to all first year students. The course syllabus includes number systems, data representation, Boolean logic but also basics of data types and control structures such as functions, loops, etc. The proposed activities on introduction to robot programming (see Sec. 3.3) were most relevant to this particular course from the entire first year curricula which includes also subjects such Maths, Physics, critical thinking, academic writing, etc.

3.2 Robot Platform

(a) (b)

Fig. 1: Thymio II educational robot (a) and its programming environment (b) Aseba [2].

Based on our earlier survey [8] which looked at the existing suitable robotic platforms for teaching Computer Science at African institutions, we have selected an affordable robot Thymio II [2]. Thymio II (see Fig. 1a) is a commercial product which is available also as an open source platform for self-assembly, at the price below $150. The robot uses a mid-spec 16-bit microcontroller and includes a number of IR proximity sensors, odometry, temperature sensor, accelerometer and microphone. The robot can generate sounds and is equipped with an array of LEDs. The programs can be developed and uploaded from a PC through a USB port which is also used to charge an internal accumulator. The robot also comes with a sturdy plastic enclosure. The programming environment is based on Aseba, an open-source scripting language, which also includes a visual programming environment aimed at users without prior knowledge of programming (see Fig. 1b). The provided supplementary materials include tutorials, instructional videos and project ideas. This robot currently presents the best trade-off between price, abilities and provided supporting materials which made it an ideal platform for our activities.

3.3 Activities

The proposed pilot study formed part of workshop activities for the “Introduction to Computer Science II” course carried out in computer laboratory over three weeks (see Fig. 2). The workshop tasks were designed as a short introduction to robot programming and were rather loosely aligned with the module syllabus. The tasks included many fundamental programming concepts relevant to the second part of the course, however. Each week a different theme was conducted gradually introducing students to the robot, its programming environment and basics of robot programming. First week started with Introduction to Robot Programming where students could learn about basic robot components, the second week was designated to Further Programming which introduced different robot behaviours and more advanced concepts such as timers, loops and random number generators, and finally the third week concluded the activities with the Final Competition. The Final Competition featured a treasure seeking contest, where students were asked to adapt and merge simple robot behaviours exercised and developed in previous sessions into a robot seeking for paper "treasures" spread out on the floor around the lab. The activity was timed and number of treasures counted used as a measure of success. To incentivise the student involvement in these activities, their engagement with the activities was included in the overall assessment of the module, although with relatively low weighting (10%) due to the fact that this was part of a pre-study. The awarded marks were based on relative quality of the code and robot's performance during the task.

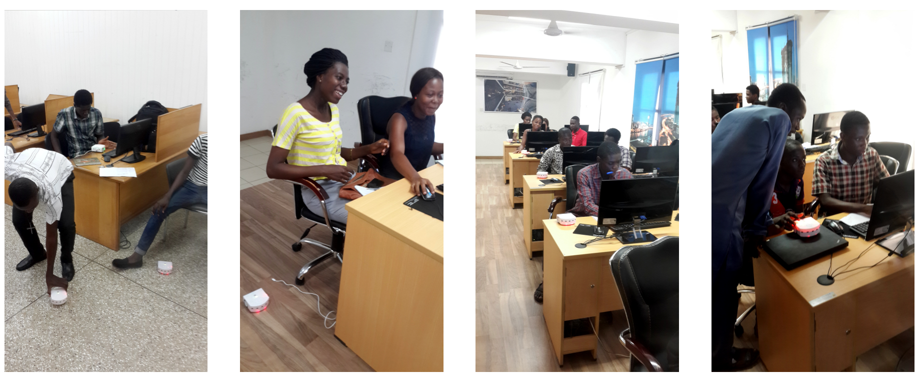


Fig. 2: Students at the Department of Computer Science, University of Ghana, participating in robotic activities.

3.4 Survey

Finally, a student survey was conducted through questionnaires to determine their interests and engagement in robotic-enhanced teaching activities. The questionnaire was designed such that students could self report and rate their learning experience and programming concepts discovered, but also their general experience and engagement with the activities, including team work. We have indicated each question by a separate label which will be used throughout the evaluation section to make the presentation more concise. The specific questions were grouped into three categories including:

- *Student background* including prior education (QB1), selected study course (QB2), gender (QB3), previous experience in working both with robots (QB4) and programming (QB5).
- *Learning experience* including programming concepts learnt (QL1), learning new programming language (QL2) and software environment (QL3).
- *Individual experience* asking students if the lab sessions were engaging (QE1), tasks intuitive (QE2), individual needs for guidance (QE3), the quality of provided help (QE4) and experience of working in a team (QE5).

In addition, the survey encouraged free comments both positive and critical to capture other issues not covered by the presented questions. The survey was completely anonymous to encourage more informed responses and focus on the group rather than individuals.

3.5 Cohort

The pilot was conducted for the first year Computer Science cohort at the Department of Computer Science, University of Ghana, during their second semester of study in Spring 2015. From the total of 197 students, 176 participated in at least one lab session and 152 participated in the final survey. The students were divided into 10 groups (roughly 20 students per each group). Because of the large size of the first year cohort and a limited number of robots (we only had 10 Thymio II robots available), the students were divided into pairs with one robot allocated for each pair. Although a limiting factor, this enabled us also to assess students abilities working in teams and observe their interactions during the activities.

4 Evaluation

The following section presents the analysis of the survey data and additional information about the overall performance of the student cohort for this particular course.

4.1 Background

The students participating in the pilot study come from various backgrounds and take different subjects as their study specialism. The majority of students declared their prior educational background (QB1) in Science (70%) with the remainder roughly split equally between Arts and Business (see Table 1). 30% of the students declared Computer Science as their major study subject (QB2). Similar figures were reported both for minors in Maths and Stats, and Arts whilst the reminder (10%) in Maths and Economics (see Table 2). 24% of participants were female students (QB3) which, despite an obvious gender imbalance,

subject	response
Science	73%
Arts	14%
Business	13%

Table 1: Educational background (question QB1).

subject	response
CS Major	30%
CS/Maths & Statistics	29%
CS/Maths & Economics	12%
CS/Other	30%

Table 2: Selected study subject (question QB2).

is a higher figure than in the majority of the developed countries (e.g. 18% in USA [12]. Fig. 3 illustrates student's prior experience with robots (QB4) and programming (QB5). There were only few confident positive responses in both categories and predictably the reported familiarity was rather low for the majority of students (this was after all their first year of study!). A bit surprising is a relatively balanced response to a question on prior experience with robots when compared to their familiarity with programming. This indicates that most likely the intended question (which should be about 'the prior experience with robot programming') was not clearly defined and many of the responses were likely referring to leisure activities involving commercial robot toys, etc.

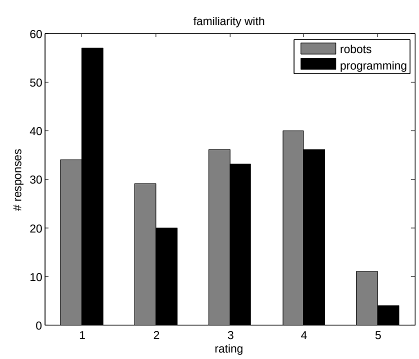


Fig. 3: Prior experience with robots and programming (question QB4-5). The rating varies from 1 - 'not familiar at all' to 5 - 'very familiar'.

4.2 Learning experience

The majority of students had little prior experience with programming so it was interesting to see if the proposed activities taught them some practical programming skills. Table 3 indicates that students were confident to report their knowledge of variables, functions and events which featured prominently in the proposed tasks. The students were less sure about more advanced topics such as counters and random number generators which were not used as often and perhaps were not explicitly highlighted in the provided tasks. This can also explain rather low responses to 'constants' category, a relatively simple concept but most likely not addressed directly in descriptions.

concept	response
constants	26%
variables	82%
functions	66%
events	76%
counters	30%
random numbers	26%

Table 3: Programming concepts learnt (question QL1).

61% responded that they benefited from learning a new programming language (QL2) but only 37% reported appreciation for learning new software development environment (QL3). It is encouraging to see that learning practical programming skills seems to be valued by the students. It is more difficult to judge if the response to the second question is related to the actual interface of the software environment or general attitude towards development tools.

4.3 Individual experience

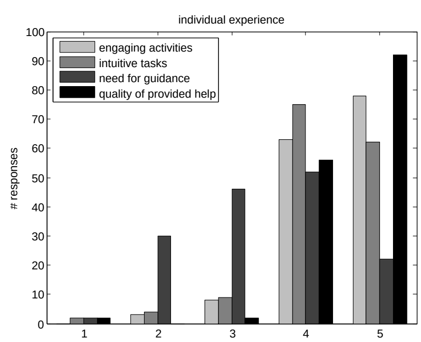
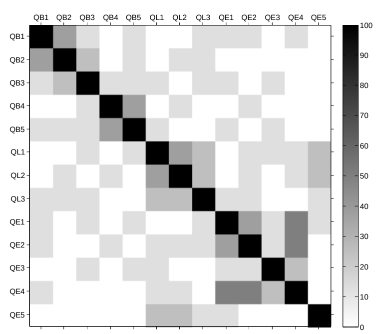


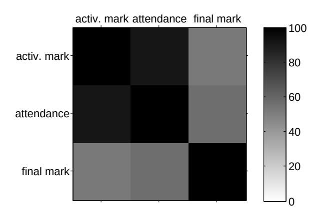
Fig. 4: Individual experience during activities (question QE1-4).

Figure 4 summarises individual student experience throughout the activities. The reported figures indicate overall positive reception of the activities. The majority of students thought the sessions were engaging and tasks intuitive. Despite that fact, the guidance was still needed and appreciated. It would be interesting to see how this aspect changes over longer period of time to see if the need for help was mainly due to novelty of the robotic activities or general trend in student learning. 86% of students reported that they liked and benefited from the team work which was also reflected in numerous free comments. It might be that collaborative learning is especially appreciated when learning completely new concepts and overshadows problems related to a constrained access to the robot.

Fig. 5a depicts correlation between different questions in a graphical format to pinpoint the potential links between the questions. Correlations mainly occurred for questions within the same category. It seems that the student background has had little impact on the learning and individual experience during the sessions. Also, the need for guidance question seems not correlated to any other factors and might describe general expectations of the students during practical sessions. In addition, students who enjoyed team work seemed to be also enjoying the learning of programming concepts, although it is less clear why these two are correlated. This might indicate some potential benefits from working in groups and opportunity to verbalise problems with understanding of certain programming concepts.



(a)



(b)

Fig. 5: Correlation between a) all question from three categories (Spearman's rank) and b) marks and attendance from activities and the final exam results (Pearson coefficient). Darker colour corresponds to stronger correlation levels.

Disclosing student marks would not be particularly beneficial for our discussions and therefore we only report general results to provide some more context. The non-engagement in the activities oscillated around 10% and included the majority of students who failed the module. This was mainly due to withdrawals caused by health issues, poor academic performance in general and other reasons. Overall, the students achieved better results from the activities than from the final exam - to give an account of any potential links links between these two factors we have calculated the corresponding correlation coefficients (see Fig. 5b). There is a strong link ($\sim$60%) between the marks achieved from activities and final exams, but also one can see a much stronger correlation between the marks from activities and the attendance profile. This is not unexpected as it would be very difficult for the students to complete the final assessed task without proper engagement in all sessions.

4.4 Analysis and Discussions

Student background did not seem to have major implications on the performance and engagement, contrary to the popular belief that students from better high schools tend to do better at the university. Obviously that aspect would have to be tested over longer period of time to allow for more informed conclusions. Despite a relatively short experience with robot programming, the students were able to learn some basic programming concepts and a new programming language. This indicates a potential for using the robots for teaching general programming skills, but will need to be addressed in more systematic way - e.g. one should investigate first what exactly students know before attempting such activities. Of course, the practical sessions need to run along well formed theoretical syllabus and it is an interesting and open problem how to evaluate the influence of each of both activities on the student's learning.

The pilot study was received very positively by the students as indicated by their responses to individual experience questions (Sec. 4.3) and numerous free comments which include terms like 'practical', 'engaging', 'interactive', etc. Other free comments demonstrate that further: students would like to see more practical sessions with the robots and also their incorporation into the regular study programme. The students participated actively in all sessions despite problems with timetabling of the activities around their other academic commitments which was one of the main critical comments provided in the feedback. Despite obvious benefits from working in teams, the students would have liked to see 'more robots' and perhaps more time they spent directly programming them.

The selected hardware platform, Thymio II robot, has proven to be a very good choice. Its functionality was rich to enable wide range of activities and programming concepts to be introduced. The robot is built in a sturdy way and with an exception of occasional faults with USB cable, all 10 robots performed without major issues. One obvious shortcoming of the platform was lack of wireless connection, which impacted on the actual time students spent trying different robot behaviours. The extra time necessary for regular re-connection of the robot to PC was especially evident in the final competition. The provided software environment enabled opportunity to familiarise students with alternative programming language and also programming paradigms; Aseba features an event-based approach. This introduced some unexpected difficulties around classic programming concepts such as loops for example, as it is less natural to provide meaningful examples in this type of paradigm. The provided online material, and especially 'Getting started' tutorials, were very helpful to instruct the students in an accessible way about basic robot functionality. In fact, the first session was almost entirely based on the provided online material.

The most evident problems encountered during the pilot study had organisational origins. Due to extra-curricular character of the sessions and rather significant resource requirements in terms of student time in the laboratories, there were systematic issues with timetabling of the sessions and clashes with other commitments. To introduce such activities in a more organised and effective way, it is necessary to embed them into the existing curricula so they are part of normal resource allocation and preparations done by the departments. Indeed, our next step is to run the extended sessions as an integral part of the same module in academic year 2015/16. Another prominent issue was related to frequent power outages which further disrupted the scheduled sessions. Such infrastructure problems are not only limited to a single African country but more prevalent across this part of the world. This is a major challenge not only for educators interested in robotics, but in general. One alternative might be to consider environments relying on mobile devices only, which require less power resources, can be powered from batteries, etc.

There are obvious limitations of the proposed pilot study. Its short duration and coverage of topics prevents us from drawing any definitive conclusions about effectiveness of educational robotics for teaching and engagement. The long-term effects, better knowledge of student background, more detailed analysis of assessment and responses were, however, outside the scope and practicalities of the study and will be addressed in future work instead.

5 Conclusions

In this paper, we presented results from a three week pilot study which evaluated a potential of using educational robots for teaching programming skills to undergraduate students at one of the African institutions. Based on the positive feedback received from students, we conclude that educational robotics is a promising direction for both improving student's learning but also their engagement in practical sessions. The proposed integrated set-up (i.e. robotic hardware, software and educational tasks) was effective and will form a solid base for a future, full scale integration of robotic activities into the undergraduate curricula. Of course, one such initiative will not be sufficient to change educational practices in developing countries and therefore it is important to consider this work as a single stepping stone in a promising direction for educators in this part of the world. To feel the positive impact of such activities, they will need to be considered at different level of education, address specific challenges of individual countries and be embedded in regular curricula.

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